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RESEARCH AND THE INDUSTRIES

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ACCORDING to the older view, an industry is composed of two elements—capital and labor. This is true to-day of the smaller and less technical manufacturing concerns. Capital supplies plant and equipment and covers the lag between expense for material and receipts from sales. Labor prepares and fabricates material according to accepted methods, keeps the plant in order and suggests improvements. The manager may be in the ranks of either capital or labor.

But a large, progressive, modern industry is operated on quite a different plan. *Capital* is represented only by a group of bankers in the dim background. The thousands of technical operatives of all grades representing *labor* follow routine instructions or work to blue prints. The vital part of the organization is the *technical expert,* everywhere directing the various departments, divisions and sections, designing new products, developing new ideas, eliminating troubles, testing raw materials and finished products. Without him the industry would go on the rocks at the first serious works trouble and even in the absence of such would be rapidly outdistanced by progressive rivals. The technical expert may or may not be financially interested in his company—it is immaterial. He is a professional solver of problems and applier of fundamental principles in quite the same sense as a physician or lawyer. He has his own capital invested in his own brain by reason of the expense for his special education and training. He represents a class quite distinct from either capital or labor, much as would a man with a special, unique machine of his own, hired for a special job.

The training of the industrial expert may be in any of a wide variety of different *fields,* ranging from statistics to science. A large progressive concern usually has at least the following separate departments: Accounts, Education, Engineering (including Research), Executive, Export, Legal (including Patent), Mailing, Publicity, Sales, Service, Treasury, Traffic and Works. In each of these (with its divisions and sections) are experts of all *grades,* smoothing out troubles, checking the work of less skilled labor, dealing with outsiders, solving general problems and finally anticipating requirements in the nature of fundamental principles by extended investigations of the principles underlying general problems. Within each grade of each field of expert knowledge individual characteristics come into play and the work may properly be made to fit the man, or rather, the man allowed to cut out his own field of endeavor according to his taste and training.

In relation to *organized knowledge*, the nation as a whole is concerned with its dissemination through education, its increase through research and its application to special problems of all kinds in all fields. The promotion of each is the self-evident course toward the ultimate goal of all our problems solved by experts, the elimination of misguided effort and the rule of common sense everywhere. The large industrial unit stands in precisely this relation to organized knowledge, but chiefly only in selected fields, and in these is concerned not so much with education as with research and the application of the results of research through engineering.

Industrial research is one of the three great classes by which the great bulk of the increase in organized knowledge is made. The investigation of fundamental laws and phenomena is naturally and probably always will be associated with our universities and our greatest teachers and leaders. We look to *university* research to advance our knowledge of the structure of the atom, gravitation, valence, relativity and similar phenomena. Problems in such fields as astronomy and astrophysics, geophysics and terrestrial magnetism are properly the charge of either university or of privately endowed research laboratories. It is the field of *national* research, directly endowed and fostered by national and state governments, to solve problems of general practical interest such as are related to public health, food, forestry, soil physics, road building, animal hubandry, education, the maintenance of standards and the development and conservation of public resources. Such problems fall outside the bounds of both industrial and university research. The existence of a number of privately owned and of cooperative research corporations in a flourishing condition attest the commercial value of research by technically trained experts.

There exists a widespread but fallacious notion that industrial research deals chiefly with cures for works troubles. As a matter of fact that represents but one extreme, the other extreme being the purest of "pure" research and the average being nearly or quite as fundamental as the average university research in physics or chemistry. Industrial research is usually directed along lines of more or less direct interest to the company, but almost invariably leads to results of general or theoretical interest. On the other hand, hardly any research is so "pure" but that it will yield some results of commercial value. In the investigation of difficult industrial problems, it is usually found necessary to continually dig deeper and deeper until the very foundations of the science are reached. Industrial research can not be distinguished from "pure" research, except that in one case it is the scientific results that are the by-products, while, in the other it is the results of commercial interest which are regarded as incidental. In a typical large industrial research laboratory the main line product is a series of reports from the laboratory to the chief of the division; the by-products are scientific papers and patents. It would be difficult to name a piece of research which would not be likely to yield all three classes of results: scientific, technical and patentable.

But research is exceedingly expensive and the results are very uncertain. Why is it that manufacturing concerns are so ready to start and maintain research laboratories, particularly since so much of physics and chemistry has already been worked out? In any industrial plant the need of research work and research men is usually first felt in the need of *improvements in products* and of *utilizing by-products.* The factory superintendent and his experienced foremen have been able to handle the ordinary run of works troubles and make minor improvements. But they find themselves handicapped by the lack of deeper insight into materials and their behavior. Why does one lot of material give good results and the next fail utterly even though chemical analysis reveals no difference? What is the cause of blow holes in castings and how may they be eliminated? The elimination of obscure works troubles calls for expert technical advice and no manufacturing concern can go very far without feeling the need of it. As a general rule the expert with just the required knowledge can not be found or is employed by a rival concern. If the problem is turned over to a private or cooperative laboratory, a solution of their problem may be attained, but they have no further control over the investigator, valuable by-products of the research are wasted and a crop of succeeding related problems must go unharvested. The results are far less satisfactory than when the concern has its own laboratory.

But probably the most urgent *raison d'être* for industrial research laboratories is the constant danger of being out-distanced by competitors. Of two otherwise equal concerns, one of which has plenty of skilled scientific and technical assistance and the other has not, the former is sure to forge steadily ahead of its unprogressive competitor by making more far-reaching improvements and by utilizing waste products. Even bakeries and laundries find research pays in cutting down losses and making improvements in processes. The balance is a delicate one, since the results are cumulative.

The notion that physics or chemistry is "all worked out" can hardly exist except in the mind of the student. As a typical concrete example of industrial research work let us consider the problem of condenser dielectrics. The student has learned the definition of dielectric constant and how to measure it. He knows his electromagnetic theory and the relation between refractive index and dielectric constant. He knows that constant to be an important one in organic chemistry and that it varies with frequency. But the industrial concern wishes to know what is the best dielectric to use in a given kind of condenser. That dielectric must have a high dielectric constant with high dielectric strength and low watt loss. It must be insoluble in certain oils, but soluble in certain solvents. It must be fusible, but must have high melting point and must be stable. Finally, it must be reasonable in price. The organic chemist has a rich field of fats, oils and waxes to cover; acids and esters, halogenated hydrocarbons, ketones and the like to prepare and try out. The physicist must devise new and more precise methods of measuring dielectric constant and of separating the leakage current from the displacement current in the presence of some electrolysis and polarization. All of this physical and chemical research devolves upon the industrial laboratory. The investigator is fortunate if he have a thorough grounding in the elements preparatory for this work. Any problem in this whole field is well worthy of a university laboratory and no problem can fail to yield results of scientific as well as practical interest.

Similar fields of industrial research might be cited without number: leather substitutes, magnetic materials, porcelain, varnish, glass, coke, soap, non-corrosive alloys, tool steel. In each field there are extensive groups of problems each relating to material for a different special purpose and each with its special set of requirements. In each case, the university man, entering industrial research, finds his academic training, even high-grade graduate work, to be hardly introductory to the work in hand. By digging through recent scientific literature he may find a few bits of applicable data and suggestive leads, but rarely more than this. In a few of our leading technical institutes advanced students work on actual industrial research problems and excellent results are obtained. The student takes a keen interest in his work and gets a great deal out of it, the spirit of the whole institution is enlivened and frequently both the student and the concern to which he disposes of his rights reap considerable financial advantages. If the student is careful to clear up the fundamental principles involved, even "pure" science is as rapidly enriched as by any other class of research.

In the broadest meaning of the term an *engineer* is one who applies fundamental principles to practical problems. With a thorough grounding in those principles and a taste for the practical, he rapidly becomes an expert in his chosen field, whether it be bridge-building, designing power plants, making explosives, surgery, copper reduction, banking, ceramics or radiotelegraphy. In order to become an expert it is necessary first of all to acquire a broad general knowledge of all fields related to the one chosen. Upon this must be built a thorough knowledge of the basic principles involved in that field; research is undoubtedly the best and only means of acquiring such knowledge. Then comes the technical training in solving practical problems obtained through actual solution of such problems. Finally, the expert is ready to attack any problem that he may be called upon to solve. The future of the nation depends upon the quality and numbers of its engineers. A first-class engineer is not only an expert in his chosen field, but keeps in close touch with developments in basic principles in his own field and in related fields. It must be admitted, however, that the country is full of men in positions where expert knowledge and skill would be desirable, but who have neither the thorough grounding nor an up-to-date knowledge of their chosen lines of work. May the number become rapidly fewer!

Nearly all our large industrial concerns are now in the hands of a corps of trained experts designing, superintending manufacture in its various branches, writing specifications, testing products, etc., frequently known as the engineering department. Within this department, a natural subdivision is the research division, looking after the more technical and scientific problems that arise. That division is composed largely of physicists and chemists who are experts on raw materials, on testing product, on special products, preparations, methods and processes and on uncovering obscure basic principles and relations. Such a research division falls naturally into two fairly distinct sections, the technical and the scientific. The technical or engineering research section takes care of works troubles and routine testing and looks after the initiation of new works processes. The scientific research section properly looks after the investigation of the larger and more obscure problems requiring more extended research in more or less pure science. The technical research is conveniently located within the works while the scientific research may best be carried on in special laboratories separated from the works and largely under its own management. Technical research requires men with a taste for precision work and an insight into practical problems. Scientific research requires men with subjective fertility of mind and a firm grasp of the fundamental laws and principles of physics or chemistry.

In brief, industrial concerns provide their own research divisions, because (1) the accumulated knowledge of physics and chemistry falls far short of filling their needs and (2) university research fails to provide solutions for most of the larger industrial problems. University research might be largely directed toward problems of industrial moment without being any less scientific than the present average of university research, but the results of such research would always be unsatisfactory. In most cases, further research would be required to bring the results into shape for industrial application and in any case some one concern would wish exclusive rights to their use. It is only fair that the industry reaping the chief benefits from the results obtained should bear the expense of obtaining them.

The great strides in industrial progress are in the nature of improvements in *materials, methods* and *processes* and are chiefly, therefore, the work of chemists and inventors. The physicist investigates and tests the results of both. In the typical group of problems cited above (condenser dielectrics) the chemist develops materials of promise while physical measurements test their worth. The work of the physicist is at least as important as that of the chemist, but the credit will go largely to the former. This case is typical of the vast majority of research problems. The expert called upon to test a new invention is also usually a physicist. Comparatively few valuable results are obtained by either physicists, inventors or chemists working alone.

In the ideal industrial laboratory there must be the closest cooperation between the physicists and chemists and indeed between all members of the laboratory staff. University research must always be done largely through individual effort due to its very nature and to the lack of coordinated time for research by either instructors or students. Some of the earlier industrial and national research organizations are on a similar individual plan. Each high-grade man is given a room or suite of rooms with apparatus and assistants and only his chief (if any one but himself) knows much about what he is doing. There is no regular meeting of the staff for discussion of results and no general assembly other than perhaps a weekly meeting to listen to a lecture by an outsider. The natural result is a tendency to wander into side issues and to become jealous of colleagues through ignorance of their work and objectives.

In some of the more recently organized large industrial research laboratories, cooperation and team work are carried to an extreme heretofore unknown. A system of weekly or biweekly conferences on each of the major lines of research promotes the interchange of ideas and a general knowledge of all the work going on, and thereby secures an excellent spirit of cooperation and comradeship. Each conference is attended by the men carrying on the work, colleagues interested in that work, a member of the patent department and one or more research engineers. The latter look out for patentable material and for results of probable interest in the works. The director is ex-officio chairman and directs the discussion along the most useful channels. Stenographic notes are taken of each conference, these notes being afterward revised, typed, witnessed and filed for reference. Such conferences effectively stimulate ideas and suggestions and keep research directed toward the chief objectives. Such effective team work in scientific research is new, but the results indicate that it has come to stay.

An occasional conference is given over to suggestions for new lines of research. If, after thorough discussion, a suggestion appears sufficiently promising, a grant to cover it is applied for and work initiated. A piece of work lasting a year and costing from two to ten thousand dollars is not to be lightly undertaken or discontinued.

Three forms of general assembly are found to be profitable in any research organization: (1) a meeting to present and discuss the work (scientific paper or technical report) of members of the staff, (2) a journal meeting dealing with the current periodical literature and (3) topical lectures in groups of three to five lectures by some expert member of the staff or outsider on his own specialty, chiefly for the benefit of the younger members of the staff. Men who have joined the staff without much advanced university work are always a problem in the older, larger laboratories. Their advancement can not be as rapid as it might had they a full university training, it is difficult for them to drop out for further university work and, unless some such lectures are provided, the less mature men are liable to stagnate.

The *technical research* wing of the research division of a large concern is properly about equal in size or somewhat larger than the scientific research section and is made up of chemists, physicists and engineers. Their work is necessarily varied in character. It ranges from chemical analyses of raw materials and the testing of products to the elimination of works troubles and the testing and installation of new manufacturing processes. Such work requires men with a taste for routine testing, precision measurements or for the application of scientific data to concrete problems. On the other hand, men with high originality and a tendency to theorize belongs rather in the scientific wing of the research division.

Another function of the research division is to prepare men for the higher executive positions and to train specialists to take charge of special fields of advanced technical research. Men who have had a full academic course, supplemented by several years of research work in an industrial laboratory, make the best of timber from which to select *executives* and high-class *specialists*. There is at present a strong tendency to fill the higher-salaried positions only with university men with research experience and such is the avowed policy of a number of our largest manufacturing concerns. Workmen in the shops may rise to be foremen, but no farther; superintendents, chiefs of divisions and heads of departments must be university men with technical experience.

The best *preparation* for industrial research as a profession is a thorough and broad grounding in the fundamental principles of the field chosen. The student should not specialize too early nor too highly or he will fail to obtain command of related fields of science or engineering. In quantity and breadth of academic preparation the standard to be chosen is about that required for the doctor's degree in our best institutions. The new men preferred at research laboratories are men with doctorates who have published half a dozen scientific or technical papers. Men with less preparation are under a handicap and do not advance as rapidly as a rule.

Summary

The essentials in a successful modern industry are capital, labor and the technically trained expert. Only rule-of-thumb, relatively unprogressive concerns are possible without scientific specialists.

The numerous departments of a large concern require the services of a wide variety of experts. Engineers are experts in the application of organized knowledge. The research division is a branch of the engineering department and consists of two wings devoted to scientific and technical research.

Technical research is devoted to the testing and specification of materials, checking product, initiating new processes and the elimination of incidental works troubles.

Scientific industrial research is devoted to the extended investigations of basic principles and relations to the more obscure and fundamental works troubles and to the development of correct testing methods.

The research division as a whole is, in addition to the above, a training ground for men for the higher executive and technical positions.

The best academic foundation for industrial research as a profession is a broad and thorough grounding in the fundamental principles and relations in the chosen field of activity.